# METHOD OF OBSERVING SEA ICE

Technical Field

The present invention relates to a method of performing a sea ice observation for the thickness of sea ice or the like by using a synthetic aperture radar (SAR).

Background Art

Many areas (e.g. the Sea of Okhotsk) in the world have seasonal sea ice zones. The extent of the seasonal sea ice zone and the sea ice volume greatly affect the energy exchange between the atmosphere and the ocean. For this reason, it is an important factor for meteorological observation to detect a seasonal sea ice zone.

In particular, thin ice having a thickness of not more than 30 cm is of critical significance in controlling the heat, salt, and vapor fluxes at the ocean surface. Thus, detecting and classifying the thin ice using remote sensing technology is of particular importance.

Up to now, many researches for a distribution of sea ice thicknesses or classification of ice types are performed by using a microwave radiometer or a synthetic aperture radar.

However, data obtained from these researches are rarely discussed in relation to actually observed values of ice thicknesses except for comparison with observed values of ice

thickness obtained by a submarine-borne sonar in the polar zones.

Especially, the Sea of Okhotsk has few actual measurements of ice thicknesses. The actual measurements have been rarely compared with values obtained by a microwave sensor/radar.

Therefore, the present invention has as object to provide a method of observing sea ice for calculating an ice draft of desired sea ice from data obtained by a synthetic aperture radar.

Disclosure of the Invention

In order to solve the above problem, a method of observing sea ice according to the present invention has the following components.

That is, an ice thickness/drifting velocity observation of sea ice by using an ice thickness measurement sonar and a current meter moored into the sea and a sea ice observation by a high-resolution airborne SAR are synchronously performed to calculate a correlation between a draft profile of sea ice passing over the sonar and an SAR backscattering coefficient profile. The method of observing sea ice is characterized in that an ice draft of desired sea ice is calculated from the relational expression and an SAR backscattering coefficient.

In this case, as the SAR backscattering coefficient, a backscattering coefficient of L-band HV polarization may

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be used.

A backscattering coefficient of X-band VV polarization is preferably used as the SAR backscattering coefficient to detect thin ice having a thickness of not more than approximately 10 cm.

A ratio of a backscattering coefficient of X-band VV polarization to a backscattering coefficient of X-band HH polarization may be used.

Brief Description of Drawings

Fig. 1 is a map showing an observation area, Fig. 2 shows L-band and X-band polarization synthetic photographs of sea ice obtained by two SAR observations, Fig. 3(A) shows a draft profile along a sea ice track, Fig. 3(B) shows a standard deviation profile of the ice draft, Fig. 3(C) shows a backscattering coefficient profile of L-band HH polarization, Fig. 3(D) shows a backscattering coefficient profile of L-band VV polarization, Fig. 3(E) shows a backscattering coefficient profile of L-band HV polarization, Fig. 3(F) shows a backscattering coefficient profile of X-band HH polarization, Fig. 3(G) shows a backscattering coefficient profile of X-band VV polarization, Fig. 3(H) shows a backscattering coefficient profile of X-band HV polarization, Fig. 4 is a graph showing a correlation between an ice draft and a backscattering coefficient of L-band HV polarization, Fig. 5 is a graph showing a correlation between

an ice draft and a backscattering coefficient of X-band VV polarization, Fig. 6 is a photograph showing an image obtained when a backscattering coefficient of an L-band HH polarization SAR image is converted into an ice draft, Fig. 7 is a diagram showing a classification result of sea ice obtained in the three stages of open water, thin ice, and thick ice, and Fig. 8 is a flow chart showing a method of classifying open water, thin ice, and thick ice.

Best Mode for Carrying Out the Invention

An embodiment of the present invention will be described below with reference to the drawings.

In this embodiment, a relational expression between actual measurements of ice thicknesses obtained by a sonar and data obtained by an SAR is obtained from observations performed on the Okhotsk coast of Hokkaido. However, the method according to the present invention can be applied to an arbitrary sea ice observation in another region. Although the SAR is borne on an airplane, the SAR can be properly borne on a flying object such as an artificial satellite or flying balloon.

The present inventor performed an ice thickness/drifting velocity observation by using an ice thickness measuring sonar (IPS: Ice Profiling Sonar) moored into the sea and a current meter (ADCP: Acoustic Doppler Current Profiler). In sync with this IPS/ADCP sea ice observation, a sea ice observation was

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performed by a high-resolution airborne SAR (Pi-SAR). A correlation between an ice draft profile of sea ice that is actual measurements of ice thicknesses of sea ice passing over an IPS and an SAR backscattering coefficient profile will be described below.

The SAR observation was performed twice at a 20 hours interval on the Okhotsk coast.

During the two observations, the weather conditions were relatively calm, i.e., the average wind speed was 3.5m/s and the air temperature ranged from -12 to 0°C, and the sea ice mainly moved from the east-southeast to the east.

An observation area is shown in the map in Fig. 1. L-band and X-band polarization synthetic photographs obtained by the two SAR observations are shown in Fig. 2 (HH polarized wave is indicated in red, VV polarized wave is indicated in green, and HV polarized wave is indicated in blue). In Fig. 2, upper left and right photographs respectively show an X-band polarization image and an L-band polarization image at the same point, and lower left and right photographs respectively show an X-band polarization image and an L-band polarization image at the same point different from the above point. A line described in the L-band polarization image is a track of sea ice passing over an IPS obtained from an ADCP, and an upper right end point of a line in the upper L-band polarization image and a lower left end point of a line in the lower L-band

polarization image are positions of the moored IPS.

A moving distance of sea ice was approximately 7.6 km, and an average ice velocity was 10 cm/s.

Fig. 3(A) shows an ice draft profile along a track of sea ice.

An average ice draft was 0.49 m, and the maximum value was 4.77 m.

Fig. 3(B) shows a standard deviation profile of ice drafts obtained at five neighboring points at 0.5-m intervals.

As shown in Fig. 3(B), the standard deviation profile of ice drafts well coincides with the ice draft profile.

It was understood that large values of ice drafts and standard deviations (over 1 m) were often observed at the rim of ice floes. For this reason, it was supposed that very thick ice having a thickness of not less than approximately 1 m was formed by rafting and ridging at the rims of the ice.

Figs. 3(C), 3(D), 3(E), 3(F), 3(G), and 3(H) show backscattering coefficient profiles (antilog) of L-band HH polarization, L-band VV polarization, L-band HV polarization, X-band HH polarization, X-band VV polarization, and X-band HV polarization, respectively.

The correlation between the ice draft profile and the backscattering coefficient profile of the L-band HV polarization was better than the correlations between the ice draft profile and the backscattering coefficient profiles of the other band

polarizations, and the correlation coefficient was 0.64.

The backscattering of the cross-polarization (HV) is mainly caused by multiple scattering and volume scattering and is not related directly to the ice thickness. This suggests that the surface roughness formed by collision of the rims of ice causes the large backscattering.

As is apparent from Fig. 3(G), the backscattering coefficient profile of X-band VV polarization is rarely related to the ice draft profile. However, the backscattering coefficient profile of X-band VV polarization is characterized in that extremely backscattering can be obtained by very thin ice (not more than approximately 10 cm) (for example, at a 2500m point or a 4200m point).

Figs. 4 and 5 are graphs showing correlations between an ice draft (log) and backscattering coefficients (dB) of L-band HV polarization and X-band VV polarization. A regression line is calculated from Fig. 4 as follows:

$\sigma$ = 7.3 log (d) - 28.4 dB

(where d is the ice draft).

It is considered that the dispersion of the backscattering values from the regression line is mainly caused by small differences in the observation points of the IPS and the SAR.

An image obtained by converting the backscattering coefficient of an SAR image in an L-band HH polarization image shown in the lower right in Fig. 2 into an ice draft by the

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above equation is shown in Fig. 6.

According to Fig. 6, it can be confirmed that an ice thickness is large at the rim of ice. An area having an ice thickness of not less than 1 m is approximately 15% of the entire area of the ice. The volume in the area corresponds to 1/3 of the entire volume.

On the other hand, according to Fig. 5, the following characteristics were understood. That is, a backscattering coefficient profile of X-band VV polarization increases in thin ice, and a polarization ratio (VV/HH) increases. For this reason, ice type classification for SAR images was performed by using X-band HH and VV polarizations. The classification was performed on the basis of definition of WMO on the three stages, i.e., open water, thin ice (Nilas and Gray ice each having a thickness of not more than 15 cm), and thick ice (gray-white ice having a thickness of not more than 15 cm and first-year ice).

Fig. 7 is a diagram showing the classification results. Fig. 8 is a flow chart showing a method of classifying open water, thin ice, and thick ice.

According to Fig. 7, it could be confirmed that the thin ice made up approximately 8% and extended between the rim of the one-year ice and the open water.

Industrial Applicability

The method of observing sea ice according to the present invention has the above configuration to achieve the following advantages.

That is, an ice thickness/drifting velocity observation of sea ice by using a moored ice thickness measurement sonar and a current meter and a sea ice observation by an SAR are synchronously performed, actual measurements of ice thicknesses by the sonar can collate with data obtained by the SAR, and a correlation between a draft profile of sea ice passing over the sonar and an SAR backscattering coefficient profile can be calculated. An ice draft of desired sea ice can be calculated from the relational expression and an SAR backscattering coefficient.

In particular, when a backscattering coefficient of L-band HV polarization having a high correlation coefficient is used as the SAR backscattering coefficient profile, sea ice observation can be easily performed at high accuracy. A backscattering coefficient of X-band VV polarization which can obtain extremely large backscattering in thin ice is used as the SAR backscattering coefficient to effectively detect thin ice having a thickness of not more than approximately 10 cm. Since the backscattering coefficient of X-band VV polarization is rarely related to the ice draft, thin ice having a thickness of not more than approximately 10 cm can be detected by using a ratio of the backscattering coefficient of X-band

VV polarization to a backscattering coefficient of X-band HH polarization.